There are an estimated 2,000 kilometre-sized asteroids regularly buzzing Earth as they orbit the Sun.

THE COSMIC SHOOTING GALLERY

BY GEOFF McNAMARA

THE ASTEROID APPROACHED EARTH from the direction of the Sun, and that's probably why nobody knew it was coming. Travelling at 75,000 kilometres per hour, the house-sized boulder had the potential impact energy to destroy a large city. It missed the Moon by 200,000 kilometres—a tiny distance in astronomical terms—and then blindly flew on toward the Earth.

The 'Near-Earth Asteroid' (NEA) approached our blue planet early on the morning of 20 May 1993 as Australia slept. NEAs, also known as 'Near-Earth Objects' (NEOs), are simply big rocks anywhere from a few tens of metres to kilometres across that approach Earth at a typical speed of 70,000 kilometres per hour. Two decades ago they were considered uncommon and so relatively harmless. Now astronomers are finding dozens of NEAs each year and are worried that an NEA could call in on Earth...in a big way.

AUSTRALIAN PICTURE LIBRARY

Viewed from the Moon, the Earth looks like a safe place to be, but collision with just one large asteroid could change all that, as it did for the dinosaurs 65 million years ago.

This time the Earth was safe. The NEA, christened '1993 KA', missed Earth's surface by a scant 140,000 kilometres. Eight hours later it was spotted by an astronomer searching for NEAs from Kitt Peak Observatory in the United States. Only after plotting the asteroid's path through space did astronomers realise just how close 1993 KA had come. The fact that it missed Earth was simply a matter of chance: it's hard to believe, but the Earth is in the middle of a cosmic shooting gallery.

The idea of objects crashing into planets isn't new to astronomers: one quick look at the Moon's heavily cratered surface tells you that collisions between asteroids and planets have happened in the past. What astronomers are beginning to find out, however, is just how probable a future impact on Earth is. Based on the number of recent discoveries, there are an estimated 2,000 kilometre-sized NEAs regularly buzzing Earth as they orbit the Sun. Added to these are comets—large lumps of ice and rock. Any one of these objects could smash into Earth causing inestimable loss of life. For example, if a 20-metre-wide asteroid struck the Earth, it would explode with a force 20 times more powerful than the bomb that destroyed Hiroshima. If such an impact occurred over a city, millions of people would lose their lives. The collision of a ten-kilometre-wide object could lead to the obliteration of most life on Earth.

"Each human on this planet runs a risk of about 1 in 20,000 of dying from a cosmic collision", said Ken Russell, Resident Astronomer at the United Kingdom Schmidt Telescope at the Anglo-Australian Observatory in northern New South Wales. Russell and his colleagues have been using the 'UK Schmidt' to search for NEAs so that potentially dangerous objects can be found well in advance; given enough notice a major natural disaster could then possibly be averted. But so far NEA search efforts in Australia and overseas have been poorly supported. Russell and astronomers like him want to establish a dedicated search for NEAs, and point out that the costs are relatively low and easily justified: "The amount of money involved in setting up a survey is just trivial compared with the consequences of the Earth being hit by one of these things".

Either way, the collision resulted in the immediate destruction of life for hundreds of kilometres in every direction. But despite the severity of the explosion, the worst was yet to come.

ASTRONOMERS HAVE BEEN AWARE OF asteroids for almost 200 years. Their discovery coincided with the prediction of an unknown planet between Mars and the giant planet Jupiter. The orbits of the planets are spaced outward from the Sun at regular intervals, so when a gap showed up between Mars and Jupiter, astronomers decided to search for the 'guest planet'. In 1801 the 1,000-kilometre-wide asteroid Ceres was found in the predicted orbit. The gap seemed to have been filled. But then more objects were discovered orbiting the Sun at about the same distance as Ceres: first hundreds and then thousands. By 1992 over 5,000 asteroids had been found in a region now known as the 'asteroid belt', which completely circles the Sun. And it's expected that 10,000 asteroids will have accurately determined orbits by the turn of the century.

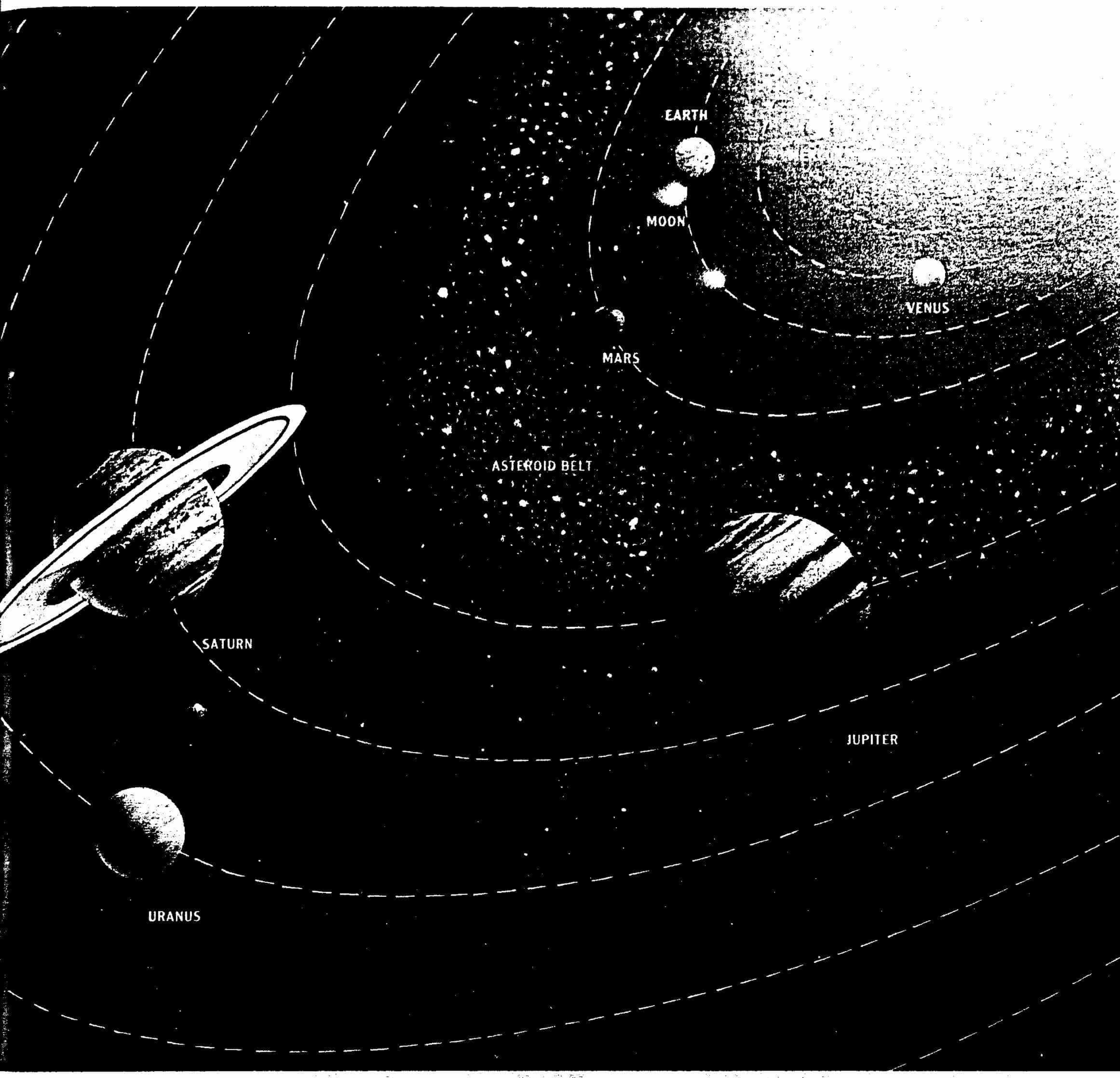
Asteroids are the debris of a planet that failed to form: the constant gravitational tugging by the giant planet Jupiter prevents these tiny worlds from coalescing into one normal-sized planet. Not all asteroids stay within the asteroid belt, however. Chance collisions between asteroids and the gravitational effects of Jupiter can send asteroids hurtling toward the inner solar system. Once there they settle down into stable orbits...some of them dangerously close to the Earth's orbit. These are the NEAs that astronomers want to keep an eye on.

Up until the 1970s little attention was paid to the possibility of an asteroid colliding with the Earth. Despite mounting evidence, such as the continuing discovery of relatively young craters on Earth and the other planets, few scientists took the idea seriously. The vast majority of craters were formed billions of years ago as the planets swept up the rubble left over from the formation of the solar system. Most astronomers believed that the chances of Earth being hit by anything in the current epoch to be, well, astronomical. Then, in 1980, a group of scientists led by father and son team Luis and Walter Alvarez published a now historic paper that turned the minds of scientists to the distant past and their eyes to deep space.

The Alvarez team found an unexpected amount of the element iridium in deep-sea limestones exposed in Italy, Denmark and New Zealand. Iridium is rare in Earth's crustal rocks, and so the anomaly was difficult to explain. But just as important as the amount of iridium was its location in the geological record—the iridium was deposited 65 million years ago, precisely matching the division between the Cretaceous and Tertiary periods, the so-called 'K–T boundary'*. The K–T boundary is perhaps more famous as the time when most of Earth's species, including the dinosaurs, became extinct. These two clues suggested that the death of the dinosaurs and the iridium deposit were somehow linked.

An earlier explanation for the iridium

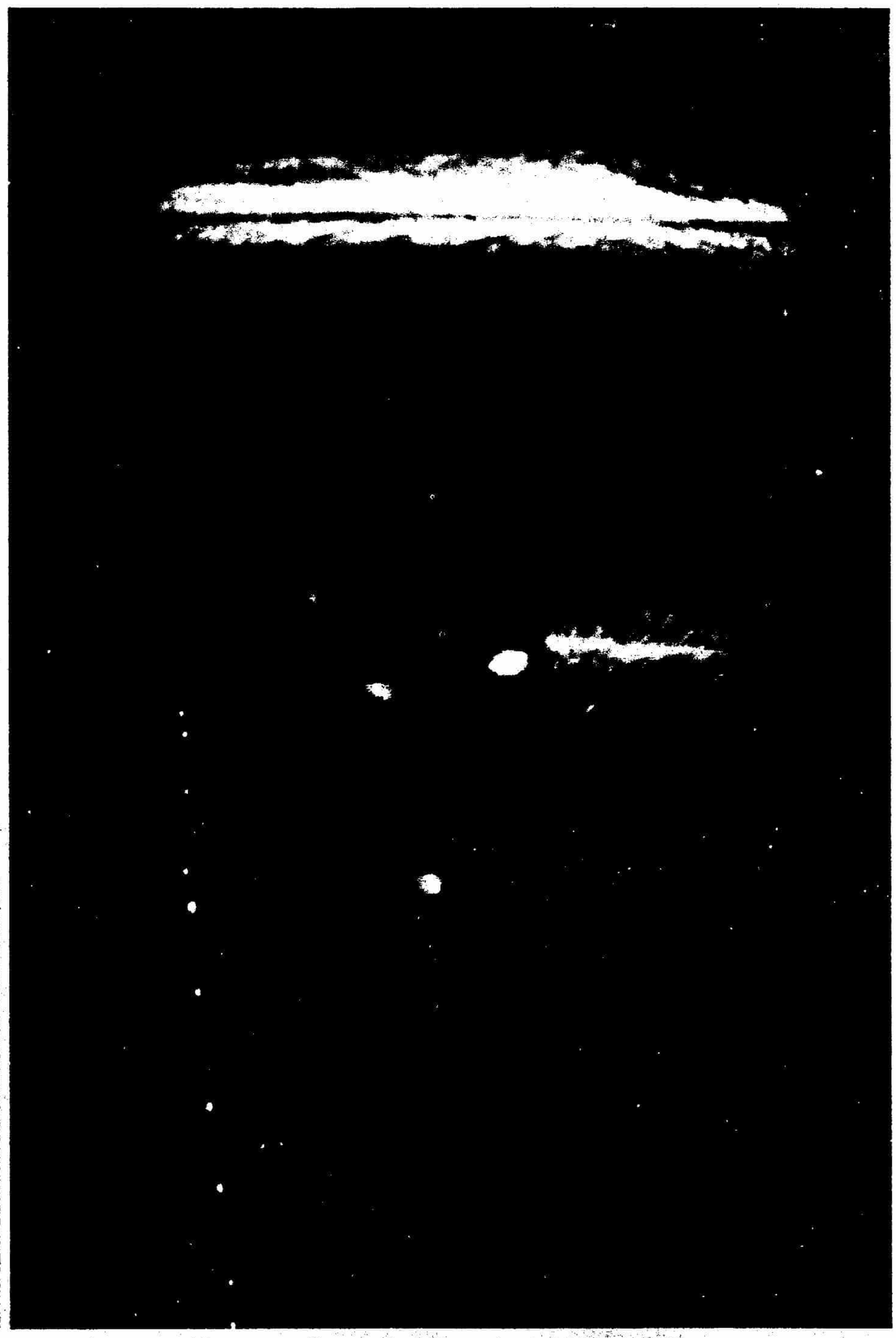
*By convention, the Cretaceous–Tertiary boundary is abbreviated to K–T because C is reserved for the earlier Carboniferous period.



Just as the planets orbit the Sun, so does a belt of asteroids that lies between Mars and Jupiter. Currently, there are over 5,000 known asteroids in this belt. (Illustration not to scale.)

was that it was brought to Earth by meteorites—small rocks that litter the solar system and occasionally land on Earth. Meteorites are rich in iridium compared with the Earth's crust. However, the average meteorite isn't likely to do more than make a loud bang as it lands; globally, life would continue unchanged. What the scientists needed to know was a way of depositing iridium over the entire planet and killing off a large fraction of the biosphere. The story the Alvarez team told sent shivers through the scientific community.

Sixty-five million years ago the Earth was struck by a ten-kilometre-wide asteroid. The asteroid was travelling some 40 kilometres per second when it entered the Earth's atmosphere, punching a 'hole' through it and throwing some of it back into space. The asteroid then slammed into the Earth with the explosive yield of 100 million million tonnes of TNT. The asteroid was instantly destroyed, being compressed and vapourised by the collision. Billions of tonnes of rock and water were thrown into the sky, leaving behind a crater 200 kilometres across. If the impact occurred in one of Earth's oceans it would also have produced huge tsunamis (large waves), kilometres high, that would have swamped the surrounding landmasses. Either way, the collision resulted in the immediate destruction of life for hundreds of kilometres in every direction. But despite the severity of the explosion, the worst was yet to come.



JET PROPULSION LABORATORY/CALIFORNIA INSTITUTE OF TECHNOLOGY, USA

An artist's impression of the Shoemaker-Levy 9 comet fragments as they began their collision with Jupiter in July 1994. The comet was broken up during a previous close pass to Jupiter and the resulting fragments are spread out along a common path, giving the appearance of a 'string of pearls'.

The many million tonnes of dust thrown up by the explosion reached the upper atmosphere and began to spread around the world. Widespread fires added soot to the dust. Within a year the entire planet was covered with an airborne layer of fine dust that blocked out the Sun. The surface of the Earth was plunged into total and impenetrable darkness. Deprived of the sunlight needed for photosynthesis, the plants died. The animals, roaming a frozen and desolate landscape, began to starve.

The darkness persisted for years; the food chains collapsed. As a direct result of that chance collision, three quarters of the planet's species died.

The theory met with stiff opposition. For one thing, where was the crater produced by the proposed impact? The chances of finding even a 200-kilometre-wide crater 65 million years after the event were slim. Unlike some other planets, the Earth's surface is dynamic. Between the effects of weathering, sedimentation and crustal movements a crater could easily have been erased millions of years ago. Nonetheless, clues began to emerge.

Scientists discovered unusual deposits of coarse rock fragments at the K–T boundary whose appearance suggested rapid transfer from one place to another by massive tsunamis. The most obvious examples showed up at sites clustered around the Caribbean basin. But surely a 200-kilometre crater in or around the Caribbean would have been noticed by now?

In 1978 a completely unrelated survey commissioned by the Mexican oil company Petroleos Mexicanos revealed a circular geological feature roughly 180 kilometres across buried under the coast of the Yucatan Peninsula, which defines the south-eastern edge of the Gulf of Mexico. The feature has been shown to be an impact crater and some scientists propose its diameter is closer to 300 kilometres. Tests of core samples revealed the crater's age: 65 million years, exactly the time that the dinosaurs vanished.

As a result of the confirmation of the age of the Yucatan crater, the impact hypothesis for the K–T extinction has been widely accepted. As Walter Alvarez puts it, "It looks to me like this is the smoking gun. This should let us stop arguing about whether there was an impact and start working on the details of the impact". Some scientists even suggest that this hasn't been the only time the Earth's species have been culled by an asteroidal impact. Evidence supporting the controversial theory that periodic extinctions are the result of periodic impacts is slight, from both astronomers' and palaeontologists' standpoints. But evidence suggesting that more than one major collision has occurred in the recent past is mounting rapidly, both on Earth and other planets. Now that scientists know what buried craters look like, they're discovering more of them. And the more craters they find, the more the question needs answering: could it happen again?

The darkness persisted for years; the food chains collapsed. As a direct result of that chance collision, three quarters of the planet's species died.

EARTH IS STRUCK BY THOUSANDS OF BITS of rock every day, ranging in size from microscopic dust particles that collide with the atmosphere and then gently float to the surface to football-sized objects that have been known to land on, or rather hurtle through, houses and even parked cars. Interesting as these meteorites are, they don't consti-

ITAR-TASS/SOVFOTO

In 1908 a 30-metre-wide asteroid exploded above the Tunguska River in Siberia. The resulting shockwave flattened 2,000 square kilometres of forest. Had the asteroid arrived a few hours later, the Earth's rotation would have put it over Europe.

tute a major hazard.

The most recent example of a major cosmic collision on Earth occurred on 30 June 1908. On that northern summer morning, a 30-metre-wide asteroid exploded eight kilometres above the Tunguska River in Siberia. It exploded with a force a thousand times more powerful than the Hiroshima bomb. The resulting shockwave flattened 2,000 square kilometres of forest: 60-centimetre-thick trees were snapped like toothpicks and felled in a radial pattern pointing away from the centre of the blast. Heat from the explosion was felt by witnesses 60 kilometres away. Despite the local devastation caused by the event, its effects didn't extend globally

The greatest threat comes from objects capable of producing global damage. An NEA one kilometre across colliding with the Earth could lead to the death of over a quarter of the Earth's population. The main cause would be climatic change, leading to disruption of the world's food production and eventually widespread starvation. The disaster could also lead to the collapse of the world's social, economic and political structures. So, while the immediate effects of the impact of a kilometre-sized object over a populated area would be the instantaneous death of millions of people, the explosion would lead indirectly to the deaths of billions of human beings.

The most detailed study of the chances of Earth being struck by an NEA or comet was carried out by Clark

SOURCES OF COSMIC COLLISION

The distinction between asteroids, meteoroids and comets used to be clear Now, astronomers realise that they are part of a continuum of objects that make up the solar system we live in. Some asteroids have turned out to be comets; both asteroids and comets produce meteoroids, and the distinction between meteoroids and asteroids is often a matter of taste. However, here is a brief guide to the solar system's inhabitants.

Asteroids

Relatively small, rocky objects that orbit the Sun with the nine major planets. Most asteroids orbit the Sun between the orbits of Mars and Jupiter, and are the remains of a planet that failed to form. However many asteroids orbit the Sun outside this 'asteroid belt' These may be 'main belt asteroids' that have been thrown out, comets that have been pulled into new orbits by Jupiter, or simply the debris left over from when the solar system formed some 4.5 billion years ago. Asteroids in orbits that pass close to Earth's orbit are called Near-Earth Asteroids (NEAs).

Asteroids range hugely in size from just over 1,000 kilometres to only tens of metres across. Below this size, it's a matter of personal preference whether you call the object an asteroid or a meteoroid!

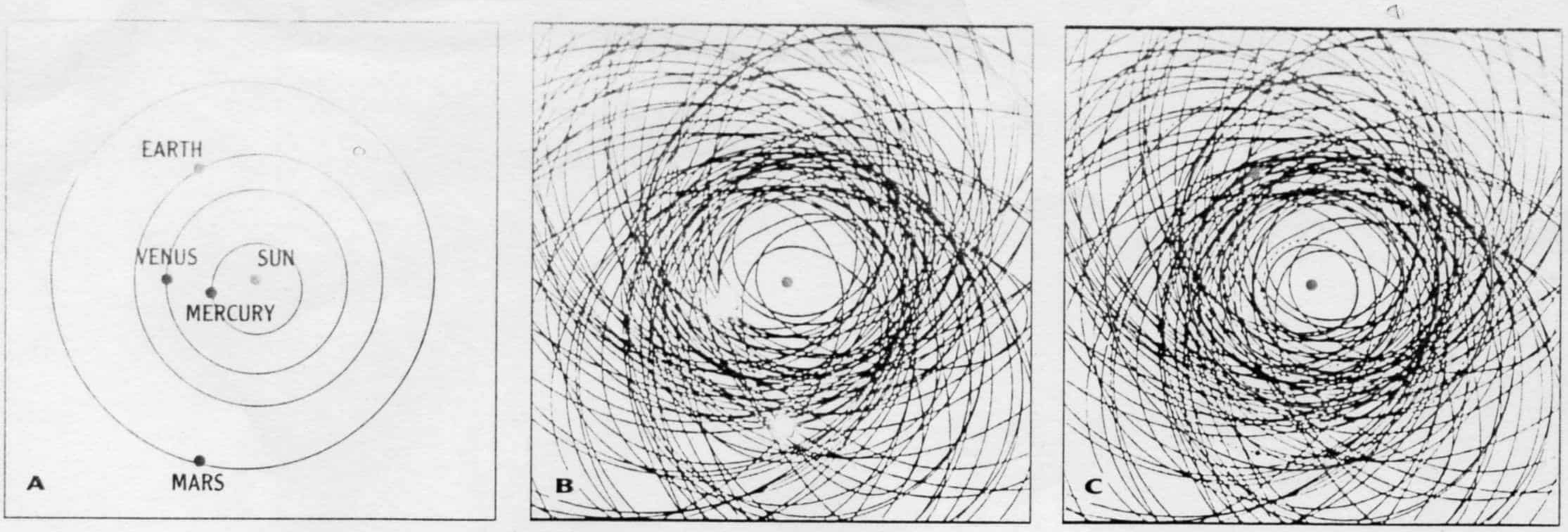
Meteoroids

In a sense, small asteroids! Most meteoroids are the remains of the formation of the solar system; many are fragments of asteroids and comets. The majority of meteoroids are dust-sized and so completely harmless to Earth. When they collide with Earth, most meteoroids burn up in the atmosphere, producing a streak of light called a meteor, or 'shooting star' Some meteoroids survive the journey through Earth's atmosphere and land on Earth's surface, and are then called meteorites. Some meteoroids make it to the surface simply because they're so small that they literally float to the ground. There are thousands of these interplanetary particles in the room you're in now, stuck to your clothes, in your hair everywhere. Other meteoroids avoid destruction because they're big enough to survive their fiery decent.

Comets

Kilometre-sized balls of ice and rock, prompting the term 'dirty snowballs' Most comets originate in the outer solar system. For reasons not yet fully agreed upon, comets occasionally 'fall' in towards the Sun and the inner solar system. As a comet approaches the Sun, its surface heats up and vapourises. These gases surrounding the comet are pushed away by the intense solar radiation, producing a tail up to millions of kilometres long. After passing very close to the Sun, the comet then swings around the Sun and returns to the outer solar system.

Some comets pass close to Jupiter as they approach or recede from the inner solar system. Jupiter's gravity can shift the comet into a new orbit. Some objects previously classified as asteroids because of their appearance and location in the solar system are now believed to be comets that have been shifted into asteroid-like orbits by close encounters with Jupiter and the other planets.



ART BY R.P. BINZEL

Although it may not seem like it, the Earth is surrounded by a frighteningly large number of asteroids and comets, as shown by this composite illustration (C) of the inner planets (A) and orbits of the 100 largest known Near-Earth Asteroids (B).

Chapman of the Planetary Science Institute in Tuscon, Arizona, and David Morrison from the NASA Ames Research Centre in California. The risk of Earth being hit by an NEA turned out to be slight. As Chapman and Morrison put it, "Impacts are an extreme example of a low-probability/high-consequence hazard"

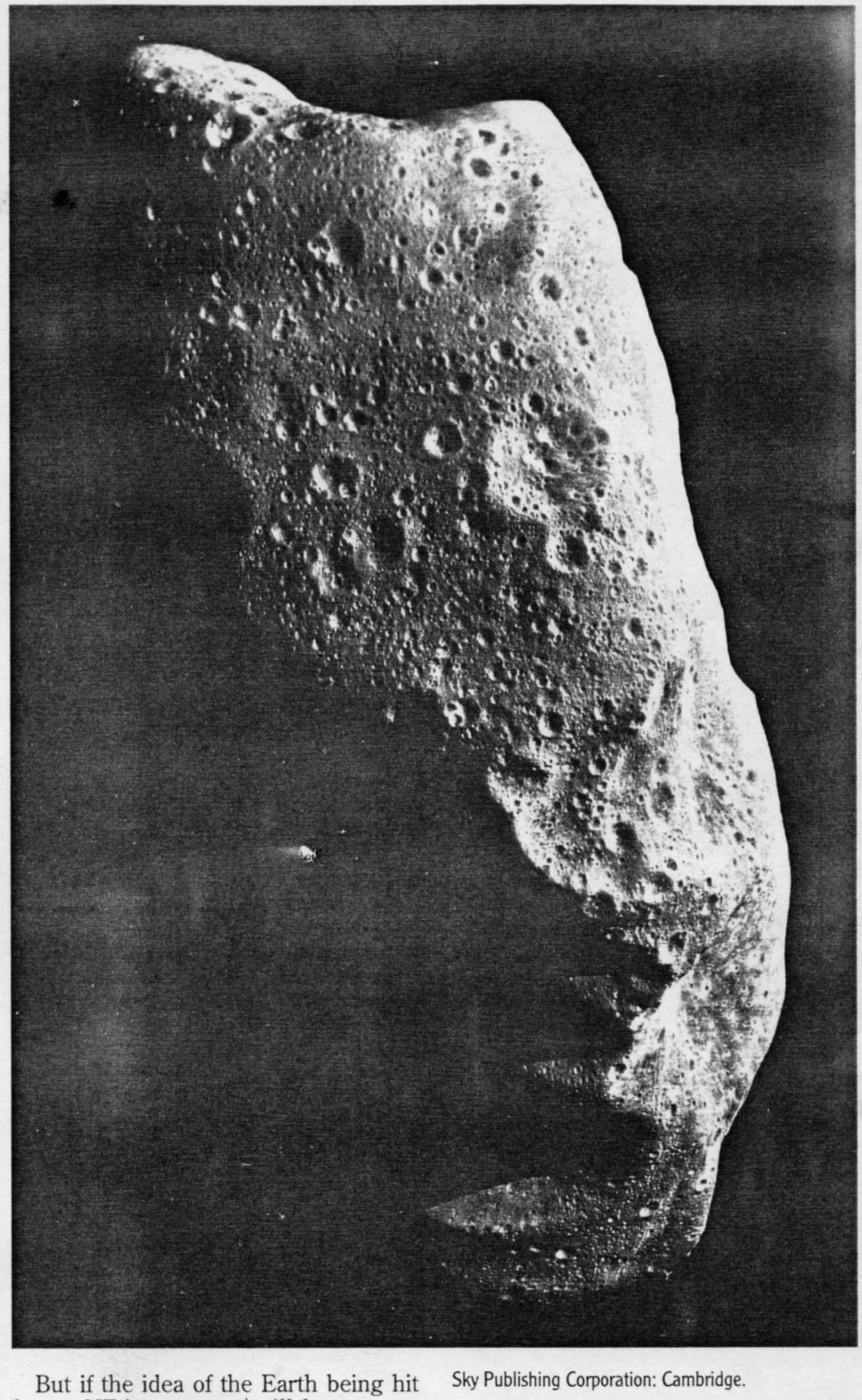
Earth is struck by more small objects than large ones simply because there are more small objects drifting through space. Chapman and Morrison calculate that impacts like the Tunguska event occur every few centuries. While such impacts could potentially wipe out millions of people, only a tiny fraction of the Earth's surface is heavily populated and so most Tunguska events occur over uninhabited areas. Larger objects strike the Earth less frequently: a 500-metre asteroid, about the smallest object capable of global devastation, strikes Earth every 35,000 years, while events like the K–T impact occur roughly every 100 million years.

For the first time in the Earth's history such a catastrophe can be avoided. About the only good thing to come out of the development of nuclear bombs is that they could be used to deflect a threatening object before it hits our planet. If an NEA or comet is found to be on a collision course with the Earth, a nuclear warhead exploded on or near the threatening object while it is still far from Earth would nudge it into a slightly different orbit so that it by-passed Earth. Successful mitigation depends on early detection, however, and this is where Ken Russell and his colleagues come in.

Since 1990 the astronomers have conducted the Anglo-Australian Near-Earth Asteroid Survey (AANEAS) using photographs taken with the UK Schmidt telescope. The UK Schmidt has a wide field of view and so is used to photograph large areas of the sky for use in surveys unrelated to AANEAS. Because most celestial objects are faint, the telescope tracks the stars while the film soaks up their feeble light. Typical astronomical exposures with the UK Schmidt can last from several tens of minutes to over an hour As asteroids and comets orbit the Sun they move against the background stars and so leave tiny trails on the photographs. If a trail is found, the object can be observed in more detail the following night to determine its orbit. The orbital information tells the astronomers whether or not the object is an NEA and, if so, whether it poses a threat to Earth.

DAVID HANCOCK/SKYSCAN

This picture of asteroid Ida was taken by the Galileo spacecraft in August 1993. Ida is the second asteroid ever encountered by a spacecraft and is about 52 kilometres in length.



JET PROPULSION LABORATORY/CALIFORNIA INSTITUTE OF TECHNOLOGY, USA

Since the AANEAS started in 1990 the astronomers have been discovering about one NEA each month They intend to expand the program by making use of the telescope during moonlit nights. The UK Schmidt is normally used to take long-exposure photographs of the night sky so that the fainter celestial objects can be recorded on the film. Most astronomers hate the Moon because it lights up the sky drowning out the light from these fainter objects. In the past this has meant that the UK Schmidt has been unused for several nights each month. But NEAs are brighter than most celestial objects, so the AANEAS team will put the telescope to good use by taking short ten-minute photographs—long enough to record an NEA without the moonlit-sky overexposing the film. A second photograph of the same part of the sky is taken later the same night. The photographs are then compared. Because the stars remain fixed relative to each other they'll be in the same positions on the two photographs. So anything that has moved between the time of the first and second photographs is not a star and is therefore looked at more closely

Astronomers want to catalogue all the NEAs so that any threat to life on Earth can be assessed and, if necessary, averted. Because of a lack of funding, however, search methods have been hit and miss—both metaphorically and perhaps literally Current searches are understaffed and poorly equipped. Even the AANEAS team has to resort to borrowed time on the UK Schmidt while it's not being used by other astronomers. The AANEAS team is grateful to the Anglo-Australian Observatory for letting them use the telescope, but it's not enough. They just cannot search enough of the sky for long enough to find all the dangerous NEAs. So far, of the estimated 2,000 NEAs over one kilometre across, only about 200 have been found by the dozen or so people involved in the search worldwide.

In 1990 NASA was asked by the US Congress to examine ways of accelerating the rate of NEA discovery NASA recommended a dedicated survey of NEAs that would take 20 years, and cost $US200 million shared internationally...truly a small amount for the insurance of life on Earth.

Gosses Bluff in central Australia resulted from a comet impact about 130 million years ago. The ring of hills visible today is all that remains of the original crater's core. Ali trace of the outer rim has been eroded over time. Satellite images of the area suggest that the original crater was approximately 20 kilometres across.

But if the idea of the Earth being hit by an NEA or comet still leaves you feeling skeptical, consider this: in July 1994, the planet Jupiter was struck by a comet that had broken into 21 fragments. The largest fragments were in excess of one kilometre across. If just one had struck the Earth it would have caused a global catastrophe. Planetary impacts are real. A collision between the Earth and an asteroid is more than just possible, it's inevitable. ■

Further Reading

Shoemaker, E.M., 1981. The collision of solid bodies. In *The New Solar System*, ed. by J.K. Beatty, B. O'Leary and A. Chaikin. Cambridge University Press & Sky Publishing Corporation: Cambridge.

Morrison, D., 1990. Target Earth: it will happen. *Sky & Telescope* 79(3): 261.

Chapman, C.R. & Morrison, D., 1994. Impacts on the Earth by asteroids and comets: assessing the hazard. *Nature* 367: 33.

Geoff McNamara has been involved in public education in astronomy for about ten years. He is a writer for Sky & Space *magazine, and writes and produces a weekly radio segment called "The Sky This Week" He would like to acknowledge the work of the Anglo-Australian Near-Earth Asteroid Survey team, which is made up of Duncan Steel, Rob McNaught, Gordon Garradd, David Asher and Ken Russell.*